ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect

Procedia Engineering 63 (2013) 53 – 59

Procedia Engineering

www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2013

Laser polishing of GGG70L cast iron with 2D scan-head

Eneko Ukar[a,]*, Aitzol Lamikiz[a], Silvia Martínez[a], Fernando Estalayo[b], Iván Tabernero[a]

[a]*Mechanical Engineering Dpt. Of University of the Basque Country UPV/EHU, Alameda urquijo s/n,48013 Bilbao, Spain*
[b]*Matrici S. Coop., Pol. Ind. Ugaldeguren III P14V, 48170 Zamudio, Spain*

Abstract

The work presented deals with laser polishing process on GGG70L spheroidal cast iron, which is widely used in die making for the automotive industry. Free graphite in the structure of GGG70L makes difficult the polishing and surface roughness reduction because the high melting temperature. In this work a complete study is presented, where main process parameters are identified and free graphite is eliminated from surface. The quantification of surface improvement is presented in terms of resulting surface roughness, hardness, and heat affected layer thickness. Thus, using optimal parameters, laser polishing with 2D scan head gives satisfactory results on GGG70L cast iron with roughness reduction rates up to 80% and minimum mean roughness Ra of 0.5 µm.

Keywords: Cast iron; laser polishing; stamping die; finishing

1. Introduction

Considering the cost structure, Huissoon et al. (2002) estimate the polishing operations on complex surfaces can reach up to 30% of total manufacturing time. In most cases, except for specific applications, the polishing of complex parts like stamping dies is still performed by highly skilled personnel using manual abrasive techniques. In a global market, to increase the competitiveness there is a need for automation of the polishing process. The automation of finishing operations would result on direct cost and delivery time reduction which are key points. In the literature it is possible to find different studies aimed at automating the polishing operations, however, due to

* Corresponding author. Tel.: +34 946014905; fax: +34 946014215.
E-mail address: Eneko.ukar@ehu.es

doi:10.1016/j.proeng.2013.08.199

the complexity of the process and the complications arising from the geometry to polish, there is no universal solution today.

Among the studies conducted can be found solutions like presented by Nagata et al. (2004) based on robot manipulators and machining centers equipped with abrasive polishing systems with various sensors to control the angle and pressure, however, its application to industrial scale is limited by two reasons. First, it is necessary a previous phase of setup for programming the robot path, although there are studies focused on getting the robot control program from machining CAM program, like the one carried out by Ryuh et al. (2006), the set-up work necessary is only justified for mass production. Second, the polishing using robot manipulators presents another serious drawback. In complex geometries with cavities or inaccessible areas, it is not possible to carry out the operation in a simple way. In these cases it is necessary to use both, tools and polishing strategies specifically tailored, complicating the process and impacting the time and cost of final production. In summary, it is a method that introduces shape restrictions and complex programming.

Laser polishing process allows a reduction in the roughness by controlled melting of material. On tests carried out on semi-finished machined surfaces and EDMed surfaces of tool steel show, Ukar et al. (2010) showed that it is possible to obtain reductions in roughness over 80% with final roughness values below 1 micron R_a using a diode laser high power. The results show the feasibility of laser polishing process and establish a relationship between the heat affected zone by the process and the initial topography. Thus, in the case of machined surfaces, thermal damage is excessive for certain applications, requiring subsequent heat treatment to correct this effect.

An alternative to limit thermal damage is to use a highly focused laser beam guided by a galvanometric head to get acceptable productivity rates. A highly focused beam, with a beam diameter at the focus below 100 microns limits the heat affected layer during processing. Perry et al. (2009), Raeymaekers and Talke (2010), Shao et al. (2005), Temmler et al. (2011) and Ukar et al. (2010), demonstrated that the laser polishing process can be successfully applied in the polishing of various materials such as titanium, stainless steel or steel tools but there are no references on the application of laser polishing process in cast iron. It is of special interest to the industry the GGG70L nodular cast iron which is widely used in molds and dies manufacturing. GGG70L casting has a metallographic structure with carbon content higher than 3% and includes particles of spheroidal graphite which present a melting point close to 3,500 K. During laser polishing process, since the melting temperature of the casting is placed on GGG70L 1,500 K, the graphite particles are not melted and tend to appear on the surface as inclusions, resulting in a rough surface. Thus, this article addresses the problems associated with laser polishing of GGG70L and proposes a surface decarburization system that minimizes the presence of graphite particles in the resulting surface.

2. Experimental tests

A series of experimental tests were carried out to determine the viability of laser polishing of GGG70L cast iron. The tests were performed using a 1kW fiber laser FL010 ROFIN guided by an optical fiber that provides a beam diameter of 100 microns to focus. The beam motion is controlled using a galvanometer or 2D scan-head HurryScan 25 from SCANLAB, which work area is 120 x 120 mm. The scan-head is installed on a machining center KONDIA B500 retrofitted as a laser cell as shown in Fig. 1.

Previous tests have shown that the laser polishing of GGG70L presents problems due to the appearance on the surface of graphite particles. Fig. 2 shows the topographic profiles before and after laser polishing a typical die and mold surface semifinished with 16mm diameter ball-nose mill and radial step of 1.5 mm. Although there is a reduction of peaks and valleys, the average roughness is similar to the initial one due to the presence of graphite in the surface. In Fig. 2 (b) it is shown the presence of graphite in the processed surface.

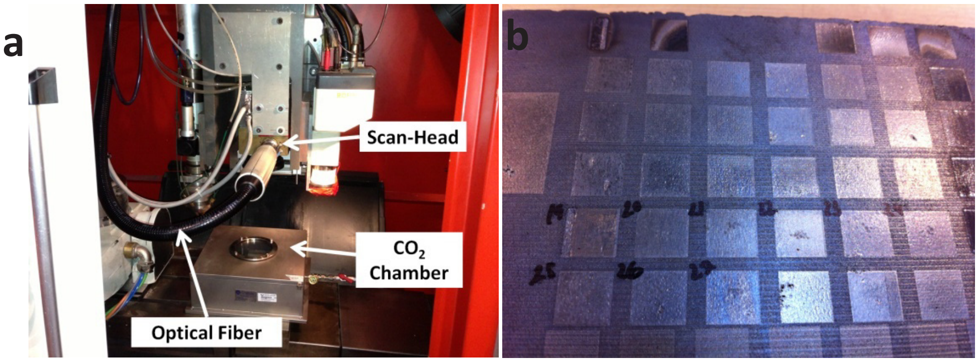

Fig. 1. (a) machine set-up; (b) experimental part.

An alternative for reducing graphite in the resulting surface is through a chemical reaction of decarburization. Following the Ellingham diagram at higher temperatures the solid carbon reacts more easily with oxygen to giving two carbon monoxide particles according to Eq. (1):

$$2C + O_2 \rightarrow 2CO \tag{1}$$

Laser polishing process increases the temperature to reach the melting of the material which promotes oxidation of different elements. Thus, if the oxygen concentration is high enough, it can eliminate carbon from the surface in what is known as decarburization.

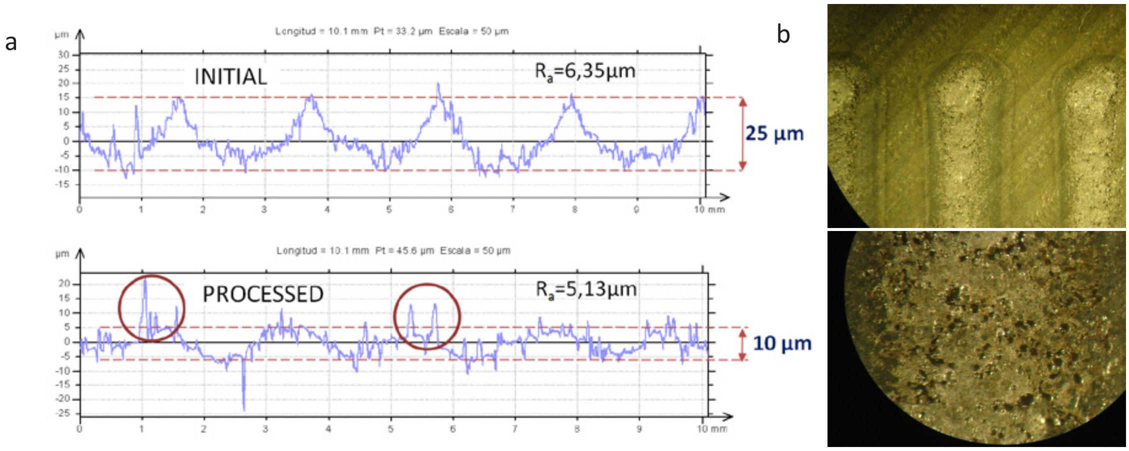

Fig. 2. (a) Initial and laser processed topography profiles on GGG70L; (b) pictures of proceed part.

The carbon in the surface can be reduced performing the process in oxygen-enriched atmosphere. However, working in an atmosphere with high oxygen concentration is dangerous due to the risk of combustion. Another possibility adopted in this study, is to perform decarburization process using a pure atmosphere of carbon dioxide so that the carbon is removed by the reaction of Eq. (2).

$$C + CO_2 \rightarrow 2CO \tag{2}$$

Working with a controlled atmosphere requires the use of a sealed chamber. The tests carried were performed using a sealed chamber of 310x310x100 mm^3 with an overpressure valve calibrated to 1.5 Bar and a crystal diameter of 120 mm transparent to a wavelength of 1,060 nm in the upper zone. The initial topography of the specimen was obtained by machining with a ball-nose end mill of 12 mm and radial step of 0.6 mm, corresponding to a typically semi-finished surface in stamping dies manufacturing. The test part was divided in areas of 10x10 mm^2 to perform different parameter combinations.

Among the main process parameters are in one hand, the beam power, the scanning speed and the spot size, which determine the energy density, and on the other hand the overlap ratio and carbon dioxide concentration in the chamber. To get best results it is important to fill the chamber with carbon dioxide and remove the air inside it. In this sense, a specific technique was developed using the different densities between air and carbon dioxide. The carbon dioxide tends to accumulate in the bottom of the volume and the air can be purged from the top. The best filling was reached with a carbon dioxide flow rate of 26L/min for 5 minutes. Later, once stabilized turbulence, the chamber can be purged to atmospheric pressure releasing the bolts of the top cover. For better result the process was repeated twice until presence of carbon dioxide in the purge flow was verified through a carbon dioxide detector Oldham CTX 300.

Regarding the spot size, the tests were carried out keeping the beam focused to avoid energy density variations within the spot due to degeneration as a result of defocusing the beam. The tests were performed with spot of 100 microns in diameter and a uniform power distribution. The parameters studied were the power (P), scanning speed (v_s) and the overlap ratio (O_i). Considering the results obtained in the preliminary tests, the range for the parameters was defined using a methodology based on design of experiments (DoE) and is listed in Table 1.

Table 1. Tested parameters

P (W)	v_s (*mm/s*)	O_i (*%*)
100	100	30
200	200	50
250	300	80

The results were evaluated based on different criteria such us surface roughness, heat affected layer thickness, surface and internal micro-hardness values and finally, the achieved productivity.

3. Results

Best results were obtained with power of 250 W, scanning speed (v_s) of 100 mm/s and overlap of 50%. Table 2 shows the mean roughness R_a and the maximum peak-valley distance R_z for tests carried out at 250 W. In the table the percentage reduction of R_a and R_z parameters as well as the surface roughness and productivity reached in each case are also shown.

Table 2. Results at power of 250 W

	P (W)	v_s(mm/s)	Overlap(%)	R_a (μm)	R_z(μm)	Reduction (%)		Hardness (HRC)	Productivity (s/cm^2)
						R_a	R_z		
Initial a_e 0,6				4,35	19,86			28,7	
Run 19	250	100	30	0,76	4,47	82,5	77,5	53,4	50
Run 20	250	100	50	0,51	3,51	88,3	82,3	50,3	20
Run 21	250	100	80	0,88	8,57	79,8	56,8	47,8	14
Run22	250	200	30	0,63	3,59	85,5	81,9	46,6	25
Run 23	250	200	50	1,05	6,46	75,9	67,5	48	10
Run 24	250	200	80	1,02	4,71	76,6	76,3	47,7	7
Run 25	250	300	30	0,8	5,01	81,6	74,8	46,8	17
Run 26	250	300	50	1,63	9,51	62,5	52,1	43	7
Run 27	250	300	80	2,45	11,38	43,68	42,7	40,9	5

Fig. 3 graphically depicts the mean roughness (R_a) values obtained for the different overlap ratios and scanning speeds. As mentioned the greatest roughness reduction is given for a 50% overlap and scanning speed of 100 mm/s. Larger overlap results in excessive heat accumulation and the generation of a melt pool which results in the formation of SOM regime and therefore less reduction in roughness. This fact is consistent with results obtained previously by Ukar et al. (2010) in tool steel polishing with direct diode laser.

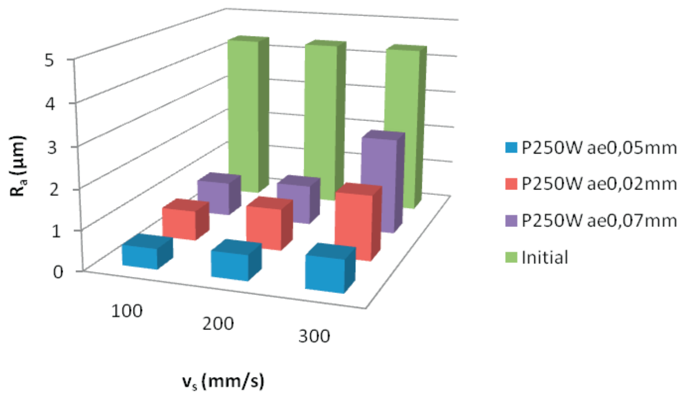

Fig. 3. Mean roughness in function of scanning speed for different overlap index.

The minimum roughness was obtained with a power of 250 W, a scanning speed of 100 mm/s and overlap ratio of 50%, which gave as result a mean roughness 0.5 microns R_a, which is enough for many applications. In cases where it is necessary higher surface requirements it will be necessary a subsequent manual finishing operation. In all cases the proposed solution minimizes the manual polishing and can also eliminate the last machining operation, since best results have been obtained starting from a semi-finished surface. Fig. 4 shows the initial and resulting topography processed with optimal parameters.

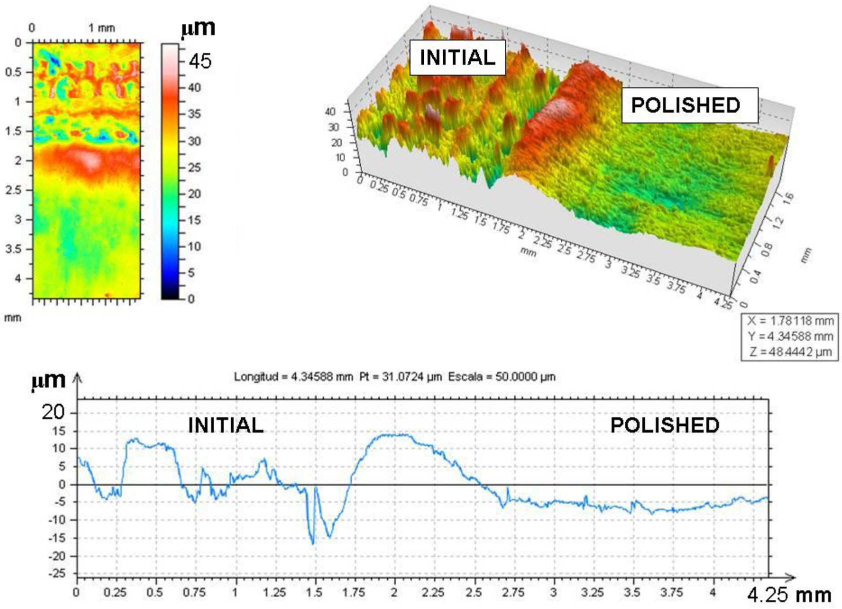

Fig. 4. Initial and polished topography.

The productivity rate obtained for the optimum process conditions was 20 s/cm^2. The time consumed in laser polishing operation is comparable to the time taken by a super-finishing machining operation. This rate of productivity can be improved using a larger spot size, which can be obtained with an optical fiber of greater diameter, or using several scan-heads at same time.

Regarding to surface hardness, in all cases there has been a hardening effect and for optimal process conditions this hardening was comparable to the hardness obtained by a conventional quenching process, with hardness values over 50 HRC. In order to verify this point and to evaluate the thickness of hardened layer, a metallographic analysis of test parts was carried out. Fig. 5 shows the structure obtained after laser polishing operation.

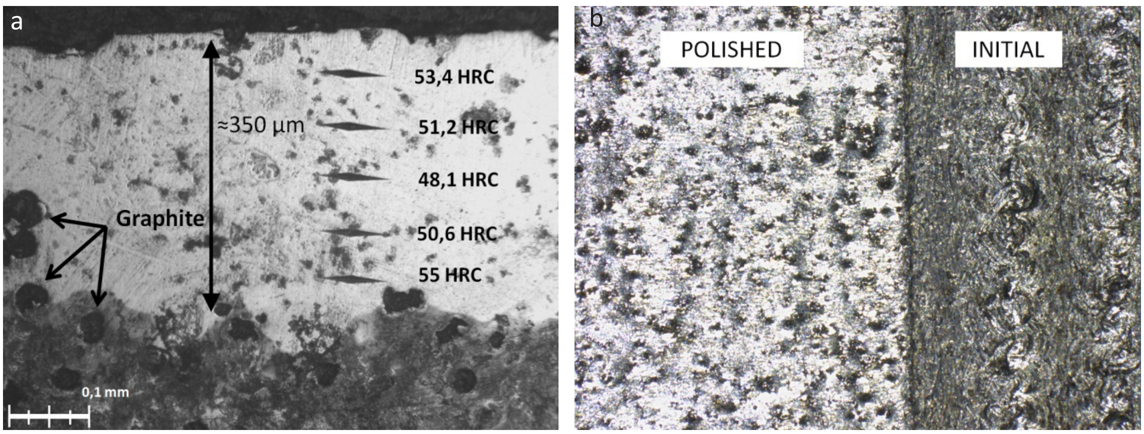

Fig. 5. (a) Hardened layer, (b) initial and resulting topography.

Parts processed with optimal process parameters present a heat affected zone, HAZ, with an average thickness of 350 microns. In this area the material presents a martensitic structure with an average hardness over 50 HRC. This effect involves the formation of uniform hardened layer all over the surface, which is a favorable effect that increases wear resistance. Regarding to the graphite particles, as effect of descarburization, the amount of particles in the process affected layer is minimized as it is shown in Fig. 5.

4. Conclusions

The application of laser polishing process on nodular cast iron GGG70L was studied. In the literature there is a lack of information about the application of laser polishing on cast iron due to the presence of graphite in the material structure. Using a chamber with CO_2 controlled atmosphere it was possible to eliminate the graphite particle on the surface by descarburization process. With the presented methodology it was possible to reduce the surface roughness in 88% from initial semi-finished surface. The resulting part presents a surface mean roughness of 0.5 microns R_a and hardened layer of 350 micron thickness, being this a favorable effect to increase wear resistance.

The productivity rate was 20 s/cm^2 and it can be improved using a guiding fiber of larger diameter. Thus, considering the results of the presented work it was demonstrated the feasibility of laser polishing process on GGG70L cast iron.

Acknowledgements

This work was carried out with the funding help received from the Competitiveness and Economy Ministry of Spanish Government through DPI2010-20317-C02-01 SURFACER project and with the funding received from UPV/EHU under UFI 11/29 program.

References

Huissoon, J.P., Ismail, F., Jafari, A., Bedi, A., 2002. Automated Polishing of Die Steel Surfaces. International Journal of Advanced Manufacturing Technology 19, 285–290.

Nagata, F., Kusumoto, Y., Watanabe, K., Yasuda, K., Yokohama, K., Omoto, M., Miyako, H., 2004. Polishing Robot for PET Bottle Molds Using a Learning-Based Hybrid Position Force Controller. 5th Asian Control Conference (2004). DOI:10.1109/ASCC.2004.184985 ISBN: 0-7803-8873-9

Perry, T.L., Werschmoeller, D., Li, X., Pfefferkorn, F.E., Duffie, N.A., 2009. Pulsed laser polishing of micro-milled Ti6Al4V samples. Journal of Manufacturing Processes 11, 74–81.

Raeymaekers, B., Talke, F.E., 2010. The effect of laser polishing on fretting wear between a hemisphere and a flat plate. Wear 269, 416–423.

Ryuh, B.S., Park, S.M., Pennock, G.R., 2006. An automatic tool changer and integrated software for a robotic die polishing station. Mechanism and Machine Theory 41, 415–432.

Shao, T.M., Hua, M., Tam, H.Y., Cheung, E.H.M., 2005. An approach to modelling of laser polishing of metals. Surface & Coatings Technology 197, 77– 84.

Temmler, A., Willenborg, E., Wissenbach, K., 2011. Design Surfaces by Laser Remelting. Physics Procedia, 12, 419–430.

Ukar, E., Lamikiz, A., López de Lacalle, L.N., del Pozo, D., Arana, J.L., 2010. Laser polishing of tool steel with CO_2 laser and high-power diode laser. Int. J. Machine Tools & Manufacture 50, 115-125.